Distortion and Elevated Growth of Instabilities by Vortices Induced by Free-Stream Nonuniformity

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The objective of this effort is to study the interaction between streamwise vorticity and Tollmien–Schlichting (TS) waves in an effort to gain new insights into the physical processes responsible for bypass transition. Transition by means of amplification and nonlinear breakdown of initially small-amplitude TS waves is only observed for low free-stream turbulence (FST) levels. "Bypass" of TS instability mechanisms has been hypothesized for higher FST levels. However, recent observations demonstrate that TS waves still play an active role at moderate FST levels. Elevated FST levels also appear to be associated with streamwise vorticity within the layer that originates at the leading edge. Therefore, the influence of streamwise vortices on TS waves may provide new insights into bypass transition, which has remained a mystery since the 1930s.

Free stream nonuniformity (FSN) is deliberately introduced into an otherwise highly uniform free stream. The FSN is in the form of a laminar wake from a fine wire (d = 0.002 inch, R_d = 16) located 7,250d upstream of the leading edge of a flat plate. Interaction of the wake with the leading edge results in a pair of weak counterrotating vortices embedded within the Blasius boundary layer. The characteristics of two-dimensional TS waves generated by a vibrating ribbon have been determined with extensive hot-wire measurements, both with and without the presence of the vortices.

The ribbon is located just upstream of Branch I of the neutral stability diagram ($F = 60 \times 10^{-6}$, R = 485) and it is active over the full span of the test section thereby allowing the wave behavior to be studied over large streamwise distances. The wave amplitude grows by almost two orders-of-magnitude between Branch I and Branch II for this operating point. The development of peak root-mean-square (rms) wave amplitude with streamwise distance conforms with predictions from linear stability theory. However, large variations in the rms wave amplitude emerge in the spanwise direction despite the relatively small wave amplitude ($u/U_1 \approx 0.5\%$). Spanwise profiles (not shown) of the rms wave amplitude have the same form of peak-valley splitting initially observed in 1962. The phenomenon is now known as K-type secondary instability and it has been subject to extensive theoretical study.

The vortices introduce considerable phase distortion of the TS waves as shown in Figure 1. Initially, the rms wave amplitude is *reduced* in the vicinity of the vortices for a substantial streamwise distance, as shown in Figure 2(a). A remarkable feature has been captured in the contours for R = 914, shown in Figure 2(b), that is, the appearance of two small regions at $y \approx 1.5$ mm with exceptionally low rms amplitude. This point marks a critical change in the wave behavior since a small increase in Reynolds number leads to a completely different distribution in which the maximum wave amplitude now occurs between the vortices, as shown in figure 2(c). A further increase in Reynolds number

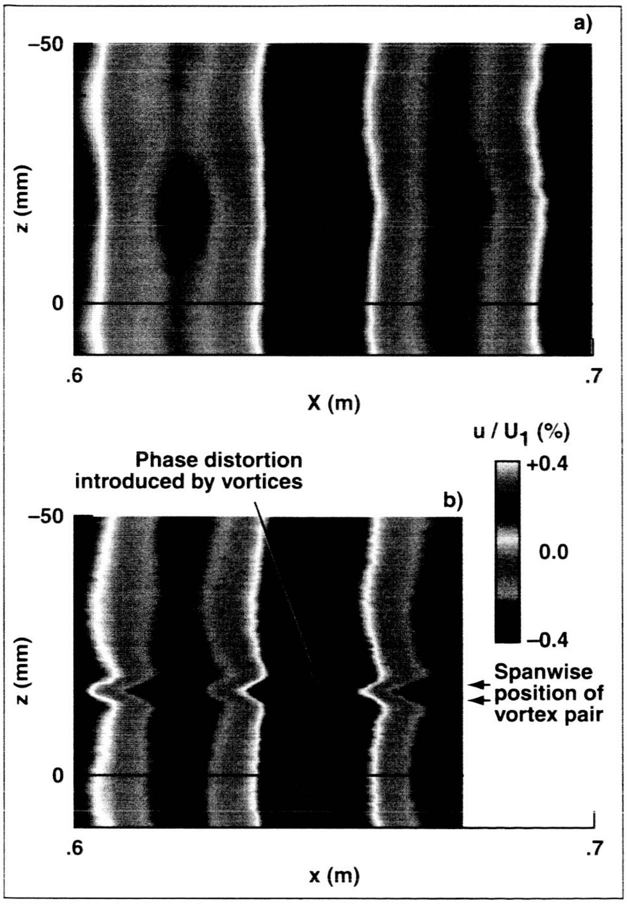

Fig. 1. Hot-wire data in horizontal plane showing phase distortion of Tollmien-Schlichting waves by FSN induced streamwise vortices embedded in the layer. (a) Without vortices, (b) with vortices.

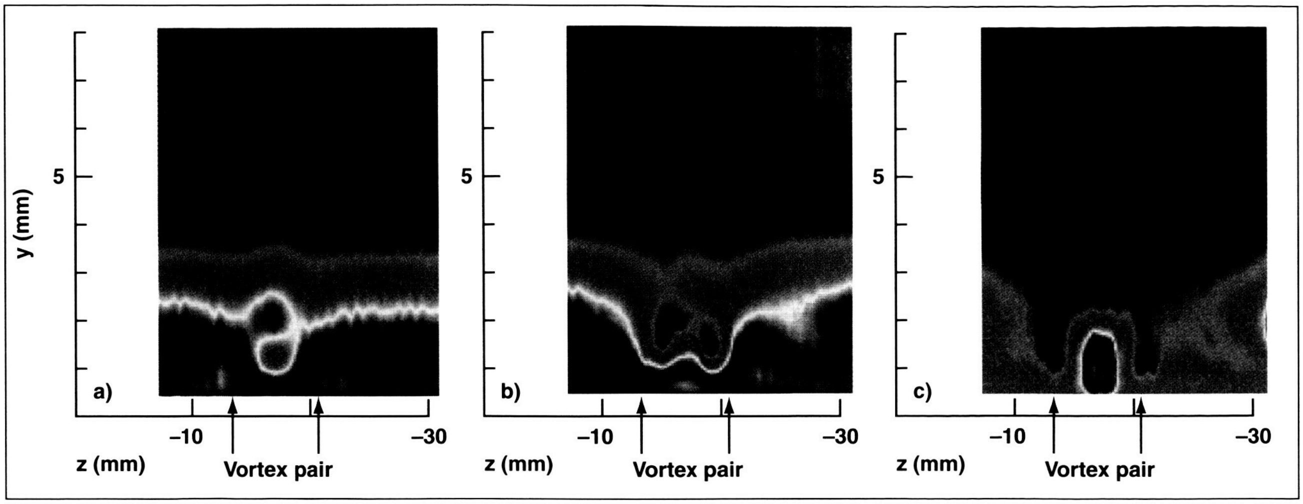

Fig. 2. Distortion of Tollmien–Schlichting wave amplitude in three spanwise planes downstream of the vibrating ribbon for the case with the FSN induced streamwise vortices embedded in the layer. (a) $x = 1.15$ m, $R = 876$ $(= R_x^{1/2})$; (b) $x = 1.25$ m, $R = 914$; (c) $x = 1.35$ m, $R = 950$.

results in rapid growth in amplitude (e.g., $u/U_1 \approx$ 10% for $R = 984$) and in the onset of random behavior, which is a characteristic of the final approach to breakdown to turbulence.

A different type of secondary instability mechanism appears to be associated with the vortices, which leads to transition at a lower Reynolds number. The results help explain the adverse effects of wind tunnel flow quality on tests concerning bodies with substantial regions of laminar flow.

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The Effects of Thin Paint Coatings on the Aerodynamics of Semi-Span Wings

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The objective of this research was to measure the effect of pressure-sensitive paint (PSP) on the aerodynamic performance of high-aspect-ratio, semi-span wings at transonic cruise and landing conditions. The PSP technique for measuring pressure distributions on wind-tunnel models requires coating the surface of the model with special paint that luminesces when illuminated by light of appropriate frequency. The technique has the potential to eliminate the need for pressure taps in wind tunnel models while yielding pressure information over entire surfaces rather than just at discrete points. The presence of paint on a model, however, can alter the flow (that is, it can become "intrusive") by adding thickness to the model or by changing the roughness of the model and thus altering the development of the boundary layer. Changes in surface roughness are likely to be most critical at high Reynolds numbers where boundary layers are thinner.

Two models were tested: (1) a single-element, supercritical wing at transonic cruise conditions in High Reynolds Number Channel 2 (HRC-2); and (2) a multi-element wing-body model complete with slats, flaps, and engine pylon and nacelle at landing